NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

No. 1468

LOW-SPEED STATIC STABILITY AND DAMPING-IN-ROLL CHARACTERISTICS OF SOME SWEPT AND UNSWEPT LOW-ASPECT-RATIO WINGS

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SUMMARY

An investigation at low speed to determine the static stability and damping-in-roll characteristics of a number of low-aspect-ratio wings including swept wings of approximately triangular plan form has been made in the Langley free-flight tunnel and the 15-foot free-spinning tunnel. The static longitudinal stability, directional stability, effective dihedral, and damping in roll were investigated for a range of lift coefficient through maximum lift.

It was found that the unswept tapered wings showed a tendency toward decreased longitudinal stability at low angles of attack as the aspect ratio was reduced. For the swept wings the neutral point moved rearward with respect to the quarter chord of the mean aerodynamic chord as the sweepback increased. In general, the effective dihedral and directional stability increased with an increase in lift coefficient and with a reduction of aspect ratio.

The unswept wings showed no consistent variation in damping in roll with lift coefficient for lift coefficients below maximum lift; whereas the triangular and swept tapered wings in general showed a reduction of damping in roll with increasing lift coefficient and in some cases became unstable before maximum lift was reached. The damping in roll decreased as expected with aspect ratio. Experimental values of the damping in roll were generally smaller than the theoretical values.

INTRODUCTION

The recent trend toward the use of low-aspect-ratio wings for high-speed flight requires that the low-speed stability and control characteristics of such configurations be determined. Some work has been done to determine the static stability characteristics of unswept low-aspect-ratio wings (for example, reference 1). The present investigation was undertaken to extend this work to include the damping-in-roll and static stability characteristics of both swept and unswept low-aspect-ratio wings. The swept wings were of triangular or approximately triangular plan form.

This investigation consisted of force and damping-in-roll tests of 18 wings having different aspect ratios, taper ratios, and sweepback angles. Most of the wings were of low aspect ratio (aspect ratio $\leqq 3$) although four wings of higher aspect ratio were included for comparison.

SYMBOLS

All forces and moments were referred to the stability axes which are defined in figure 1. The rolling, yawing, and pitching moments were all referred to the quarter-chord point of the mean aerodynamic chord. No corrections for the effects of the jet boundaries or the support strut interference were applied to the data. The symbols and coefficients used in the present paper are:

S wing area, square feet

V airspeed, feet per second

b wing span, feet

c chord, feet

$\bar{c}$ mean aerodynamic chord, feet, $\left(\frac{2}{S}\int_0^{b/2} c^2\,db\right)$

c_r root chord, feet

c_t tip chord, feet

$\Lambda_{c/4}$ angle of sweepback of quarter-chord line of wing, degrees

λ taper ratio (c_t/c_r)

α angle of attack, degrees

ψ angle of yaw, degrees

β	angle of sideslip, degrees $(\beta = -\psi)$
ρ	mass density of air, slugs per cubic foot
q	dynamic pressure, pounds per square foot $\left(\frac{1}{2}\rho V^2\right)$
A	aspect ratio $\left(\frac{b^2}{S}\right)$
C_L	lift coefficient $\left(\frac{\text{Lift}}{qS}\right)$
C_D	drag coefficient $\left(\frac{\text{Drag}}{qS}\right)$
C_m	pitching-moment coefficient $\left(\frac{\text{Pitching moment}}{qS\bar{c}}\right)$
C_l	rolling-moment coefficient $\left(\frac{\text{Rolling moment}}{qSb}\right)$
C_n	yawing-moment coefficient $\left(\frac{\text{Yawing moment}}{qSb}\right)$
p	rolling angular velocity, radians per second
$\frac{pb}{2V}$	rolling-angular-velocity factor of helix angle generated by wing tip in roll, radians
C_{l_p}	rate of change of rolling-moment coefficient with rolling-angular-velocity factor $\left(\frac{\partial C_l}{\partial \frac{pb}{2V}}\right)$
C_{l_β}	rate of change of rolling-moment coefficient with angle of sideslip in degrees $\left(\frac{\partial C_l}{\partial \beta}\right)$
C_{n_β}	rate of change of yawing-moment coefficient with angle of sideslip in degrees $\left(\frac{\partial C_n}{\partial \beta}\right)$
C_{L_α}	lift-curve slope $\left(\frac{\partial C_L}{\partial \alpha}\right)$

APPARATUS, MODELS, AND TESTS

Force and damping-in-roll tests were made on each of the 18 wings described in table 1. In order to facilitate the wing construction, most of the low-aspect-ratio wings were of flat-plate airfoil section, for past experience has shown that at low aspect ratios (approximately 2 or less) the choice of airfoils has little effect on the aerodynamic characteristics of a wing. The geometric dihedral of the mean thickness line was zero for all of the wings except wings 4 and 6, which had -0.6° and -1.9° dihedral, respectively.

The force tests were made on the six-component balance of the Langley free-flight tunnel. (For a complete description of the balance and tunnel see references 2 and 3, respectively.) The tests consisted of measurements through a range of angle of attack from small negative angles through the angle of maximum lift with angles of yaw of 0°, 5°, and -5°. The values of the lateral stability derivatives $-C_{l_\beta}$ and C_{n_β} were determined from the rolling-moment and yawing-moment data at 5° and -5° yaw.

The damping-in-roll tests were made on a rolling rig in the Langley 15-foot free-spinning tunnel (reference 4) by the method described in reference 5. The values of the damping-in-roll derivative C_{l_p} were determined from the slopes of curves of C_l against $\frac{pb}{2V}$ for several rotational speeds between $\frac{pb}{2V} = 0.1$ and -0.1 at angles of attack ranging from small negative angles through maximum lift.

All the tests were made at a dynamic pressure of 3.0 pounds per square foot which corresponds to Reynolds numbers from 166,000 to 1,150,000 based on the mean aerodynamic chords of the wings tested. The rolling, yawing, and pitching moments were all referred to the quarter-chord point of the mean aerodynamic chord.

RESULTS AND DISCUSSION

The basic data from the low-aspect-ratio investigation are presented in figures 2 to 6 and a summary of the results prepared from the basic data is presented in figures 7 to 12.

The wings have been divided into five groups for convenience in presentation and discussion, namely:

(1) Rectangular with conventional airfoil (wings 1, 2, and 3)
(2) Unswept, tapered with conventional airfoil (wings 4, 5, 6, and 7)
(3) Unswept, tapered with flat-plate airfoil (wings 8, 9, and 10)
(4) Triangular with flat-plate airfoil (wings 11, 12, 13, and 14)
(5) Swept, tapered with flat-plate airfoil (wings 15, 16, 17, and 18)

Care should be taken in interpreting the results of the present low-scale tests in terms of full-scale airplanes, although some correlation of the data for the triangular wings with full-scale tests has been obtained from unpublished force tests of a full-scale airplane of approximately triangular plan form conducted in the Langley full-scale tunnel. The static stability characteristics of the small-scale models were in good agreement with those of this full-scale airplane.

Lift Characteristics

For each group of wings the angle of attack for maximum lift increased as the aspect ratio decreased (figs. 2 to 6).

The variation of maximum lift coefficient with aspect ratio is presented in figure 7. Wing 8 with the flat-plate airfoil had a much lower maximum lift coefficient than did wing 6 which had the same plan form but a conventional airfoil section. The low maximum lift on wing 8 is attributed to a leading-edge separation at small angles of attack which is common to flat plates of moderate and high aspect ratios.

For the swept tapered wings the maximum-lift-coefficient curves were faired with the aid of additional points taken from unpublished free-flight-tunnel data on similar wings. The results of figure 7 show that the maximum lift coefficient for these wing groups reached peak values at fairly low aspect ratios (aspect ratios between 0.6 and 2.0). This result is in agreement with the data of reference 1 for straight wings and with the data of reference 6 for triangular wings with conventional airfoil sections.

The variation of the lift-curve slope C_{L_α} with aspect ratio is presented in figure 8. The theoretical variation of the values of lift-curve slope with aspect ratio for aspect ratios above 3.0 was obtained by assuming a section lift-curve slope of 0.10 per degree and applying the calculation methods of reference 7. For aspect ratios below 1.0 the following equation

$$C_{L_\alpha} = \frac{1}{57.2}\frac{\pi}{2}A$$

obtained from reference 8 was used. The theoretical curves were faired in for the aspect ratios between 1.0 and 3.0. Figure 8 shows good agreement between theoretical and experimental results and, in general, indicates that at the low aspect ratios the lift-curve slope is independent of plan form and at the high aspect ratios the experimental values of lift-curve slope are slightly less than those predicted by theory when the section lift-curve slope is assumed to be 0.10 per degree.

Longitudinal Stability Characteristics

The rectangular wings 1, 2, and 3 showed no change in longitudinal stability with a decrease in aspect ratio. The unswept tapered wings 4 to 10, however, showed at low angles of attack a tendency toward lower longitudinal stability with decreased aspect ratio similar to that previously reported in reference 1. Although for the low-aspect-ratio unswept wings 8, 9, and 10 there was no marked change of static margin $(-dC_m/dC_L)$ with aspect ratio (fig. 4), within this range of aspect ratios (3.0 to 0.5) the sweptback wings 11 to 18 showed an increase in static margin with increasing sweepback and decreasing aspect ratio (figs. 5 and 6). This effect of sweep on the static margin is illustrated in figure 9 which indicates the rearward movement of the aerodynamic center relative to the quarter chord of the mean aerodynamic chord as the sweepback increases. The extrapolated curve for the triangular wings in figure 9 indicates that the aerodynamic center is probably located at approximately the 25-percent mean aerodynamic chord for zero sweepback and approaches the 50-percent mean aerodynamic chord (or the center of area) for the hypothetical case of a triangular wing with 90° sweepback (reference 9).

On the triangular and swept-tapered wings the static longitudinal stability at the stall decreased with an increase in sweepback. Reference 10 which includes data for wing 6 and wings 9 to 17 as well as other plan forms tested at different scales shows that as the sweepback is increased low aspect ratios must be used to maintain satisfactory longitudinal stability at the stall.

Lateral Stability Characteristics

Static stability.- The effective dihedral increased with lift coefficient but, since this variation in most cases was not linear, it was not possible to compare the data for the different wings by the values of dC_{l_β}/dC_L (rate of change of effective dihedral with lift coefficient). The changes in effective dihedral with aspect ratio are indicated instead in figure 10 for an arbitrary lift coefficient of 0.4. The effective dihedral increases with decreasing aspect ratio with the greatest change at the very low aspect ratios. The experimental results are compared with the equation

$$-C_{l_\beta} = \frac{1}{57.3}\frac{2}{3}\frac{C_L}{A}$$

which was derived in reference 8. This equation was derived for triangular wings of aspect ratio less than 1.0 but a consideration of the assumptions involved in its derivation indicates that it should be applicable to wings of higher aspect ratios. Theory indicates the same general trend as the experimental results but the experimental values of effective dihedral are considerably less than the theoretical values.

The directional stability increased with increase in lift coefficient for all of the wings except wings 14 and 18. The variation of directional stability with aspect ratio at a lift coefficient of 0.4 is presented in figure 11. This figure indicates that the directional stability increases with decreasing aspect ratio except for aspect ratios below 1.0, at which, decreasing the aspect ratio decreased the directional stability.

Damping in roll.- The unswept wings 1 to 8 showed no consistent variation of damping in roll with lift coefficient except for angles of attack near maximum lift, at which the damping in roll decreased toward instability. Wings 9 and 10 showed an inconsistent variation of damping in roll through the lift-coefficient range and, in general, had less damping at the higher lift coefficients. The swept wings 11 to 18 showed a decrease in damping in roll with increasing lift coefficient before the maximum lift was reached. This decrease in damping in roll with lift coefficient for highly tapered sweptback wings is probably caused by a premature wing-tip stall.

A cross plot showing the variation of damping in roll with aspect ratio is presented in figure 12. For the flat-plate-airfoil wings, the damping-in-roll values at zero lift are given but, for the cambered-airfoil wings, the maximum values of damping in roll are given because doubtful values are obtained at zero lift because of the possible separation from the lower surface of the wing. This figure shows the usual trend of decreasing damping in roll with decreasing aspect ratio. The theoretical variation of the values of the damping-in-roll derivative C_{l_p} with aspect ratio for aspect ratios above 3.0 were obtained from reference 11. A section-lift-curve slope of 0.10 per degree was assumed. For aspect ratios below 1.0 the following equation

$$C_{l_p} = -\frac{\pi}{32}A$$

obtained from reference 8 was assumed to be valid. The theoretical curves were faired in for the aspect ratios between 1.0 and 3.0.

CONCLUSIONS

The results of the tests made in the Langley free-flight tunnel and the 15-foot free-spinning tunnel to determine the static stability and damping-in-roll characteristics of low-aspect-ratio wings may be summarized as follows:

1. Although for the rectangular wings there was no change in the longitudinal stability with aspect ratio, the unswept tapered wings showed a tendency toward decreased longitudinal stability at low angles of attack as the aspect ratio was reduced.

2. For sweptback wings of approximately triangular plan form there was a rearward movement of the aerodynamic center with respect to the quarter chord of the mean aerodynamic chord as the sweepback increased. Results indicate that for triangular wings the aerodynamic center moves from approximately 25 percent to 50 percent of the mean aerodynamic chord (or the center of area) as the sweepback is varied from 0° to 90°.

3. The effective dihedral and directional stability in most cases increased with increase in lift coefficient.

4. At low lift coefficients the effective dihedral and directional stability increased with decreasing aspect ratio except that the directional stability of the wings of aspect ratio below 1.0 decreased sharply with decrease in aspect ratio.

5. Unswept wings showed no consistent variation of damping in roll with lift coefficient except for angles of attack near maximum lift where the damping in roll decreased toward instability. The triangular and swept tapered wings in general showed a reduction in damping in roll with increasing lift coefficient and in some cases became unstable before maximum lift was reached.

6. The damping in roll decreased with aspect ratio as would be expected. The experimental values of damping in roll were generally smaller than the theoretical values.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., July 21, 1947

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TABLE 1
DIMENSIONAL CHARACTERISTICS OF THE WINGS

Wing	Plan form (Not to scale)	Aspect ratio A	Taper ratio λ	Sweepback $\Lambda_{c/4}$ (deg)	Sweepback of L.E. (deg)	Airfoil (a)	Area S (sq ft)	Span b (in.)	Root chord c_r (in.)	Tip chord c_t (in.)	MAC $\bar{c}$ (in.)
1		6.00	1.0	0	0	RSG-35	2.67	48.00	8.00	8.00	8.00
2		4.36	1.0	0	0	RSG-35	2.06	36.00	8.25	8.25	8.25
3		1.68	1.0	0	0	RSG-35	1.68	20.10	12.00	12.00	12.00
4	50 percent chord	10.00	.5	1.9	3.8	RSG-33	2.50	60.00	8.00	4.00	6.23
5	50 percent chord	6.00	.5	3.2	6.4	RSG-35	2.67	48.00	10.80	5.40	8.40
6		3.00	.5	0	6.3	RSG-35	2.67	34.00	15.08	7.54	11.73
7		2.00	.5	0	9.5	RSG-35	2.67	27.70	18.50	9.25	14.39
8		3.00	.5	0	6.3	F.P.	2.67	34.00	15.08	7.54	11.73
9		1.00	.5	0	18.5	F.P.	2.67	19.60	26.20	13.10	20.37
10		.50	.5	0	33.6	F.P.	2.67	13.88	36.90	18.45	28.70
11		3.00	0	44.9	53.0	F.P.	2.67	34.00	22.60	0	15.07
12		2.00	0	56.3	63.4	F.P.	2.67	27.70	27.70	0	18.47
13		1.00	0	71.6	76.0	F.P.	2.67	19.60	39.20	0	26.10
14		.50	0	80.4	82.9	F.P.	2.67	13.88	55.40	0	36.93
15		2.00	.2	44.9	53.0	F.P.	2.57	22.20	22.60	4.52	15.57
16		1.00	.5	44.9	53.0	F.P.	2.00	17.00	22.60	11.30	17.58
17		.33	.5	71.6	76.0	F.P.	2.00	9.80	39.20	19.60	30.49
18		.17	.5	80.4	82.9	F.P.	2.00	6.94	55.40	27.70	43.09

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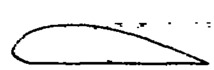
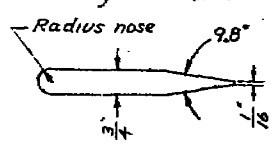
[a] *Typical airfoil sections taken in planes parallel to the plane of symmetry are shown in the following sketches:*



Rhode St. Genese 35 airfoil
(Designated as RSG, coordinates given in reference 12)



Typical flat plate airfoil
(Designated as F.P.)

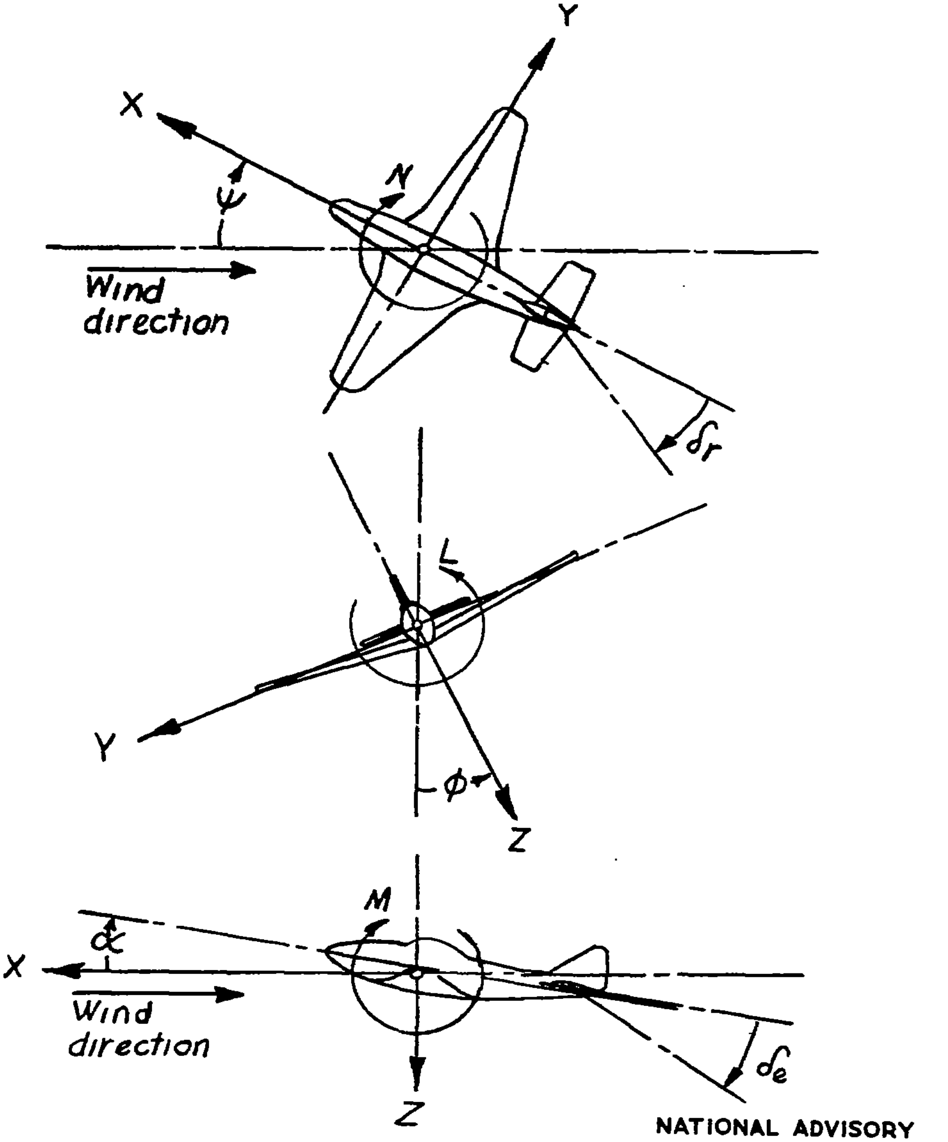


Figure 1.- The stability system of axes. Arrows indicate positive directions of moments and forces. This system of axes is defined as an orthogonal system having the origin at the center of gravity and in which the Z-axis is in the plane of symmetry and perpendicular to the relative wind, the X-axis is in the plane of symmetry and perpendicular to the Z-axis, and the Y-axis is perpendicular to the plane of symmetry.

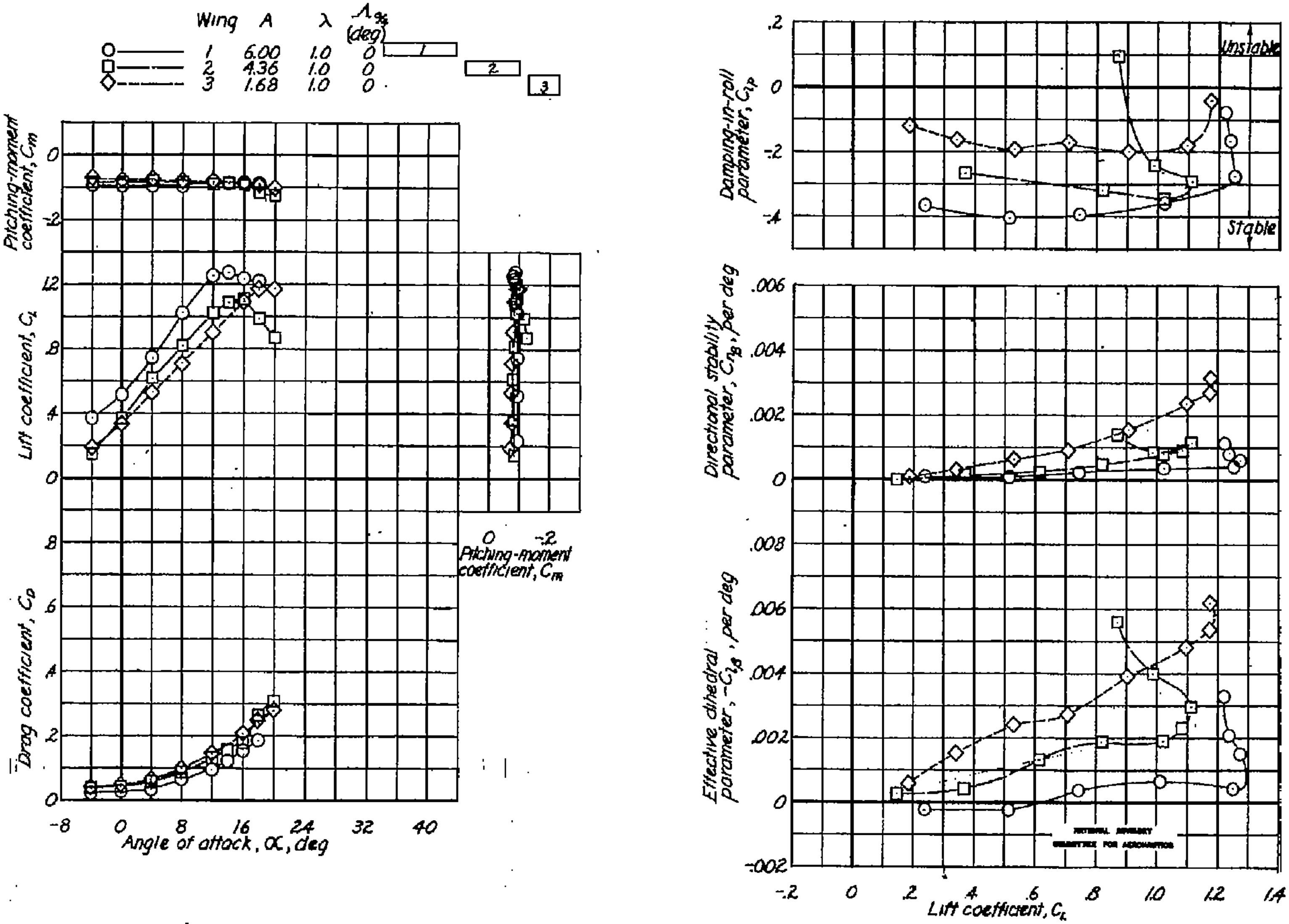


Figure 2.- Aerodynamic characteristics of rectangular wings with conventional airfoil. (Wings 1, 2, and 3 of Table 1.)

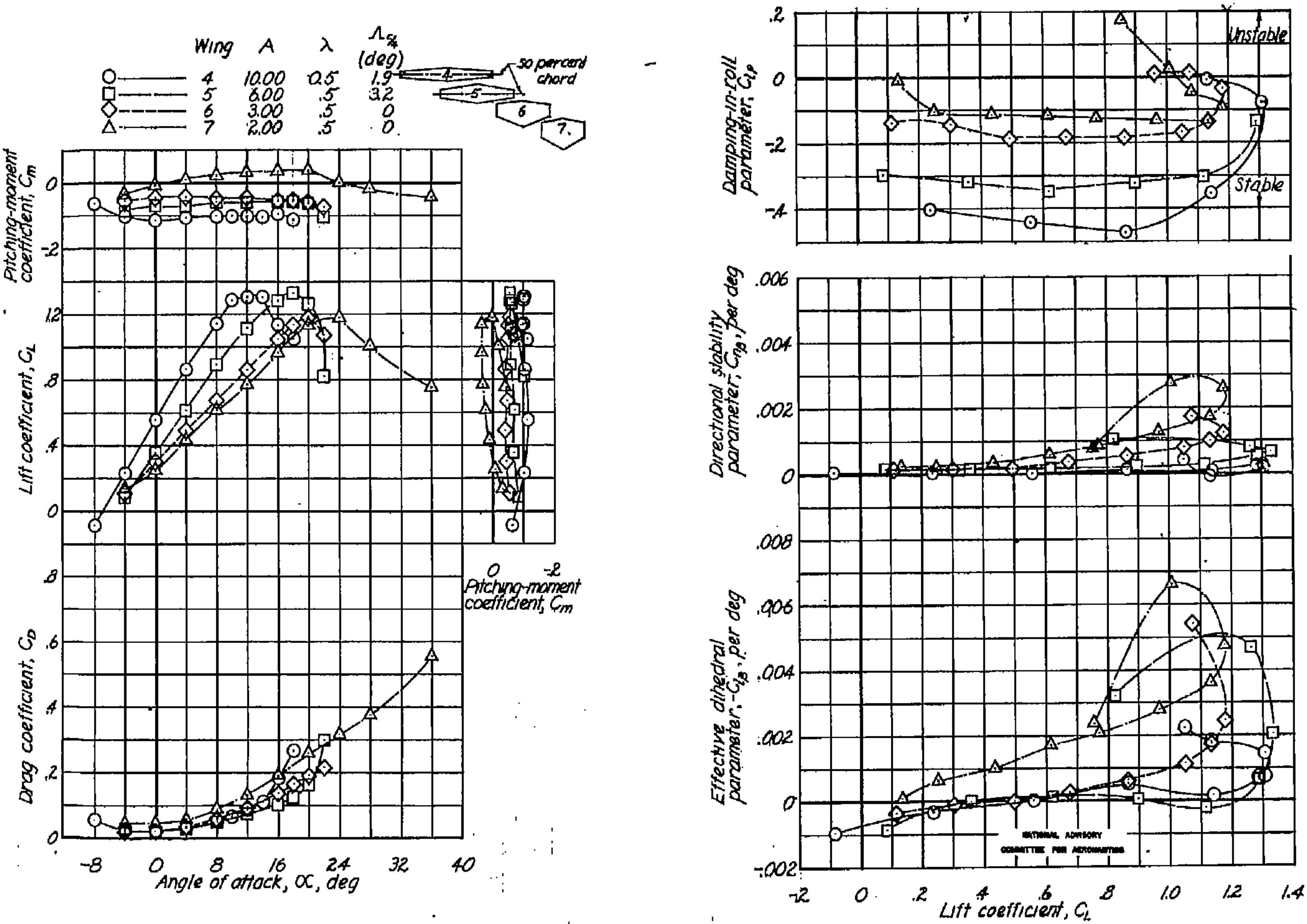


Figure 3.- Aerodynamic characteristics of unswept tapered wings with conventional airfoil. (Wings 4, 5, 6, and 7 of Table 1.)

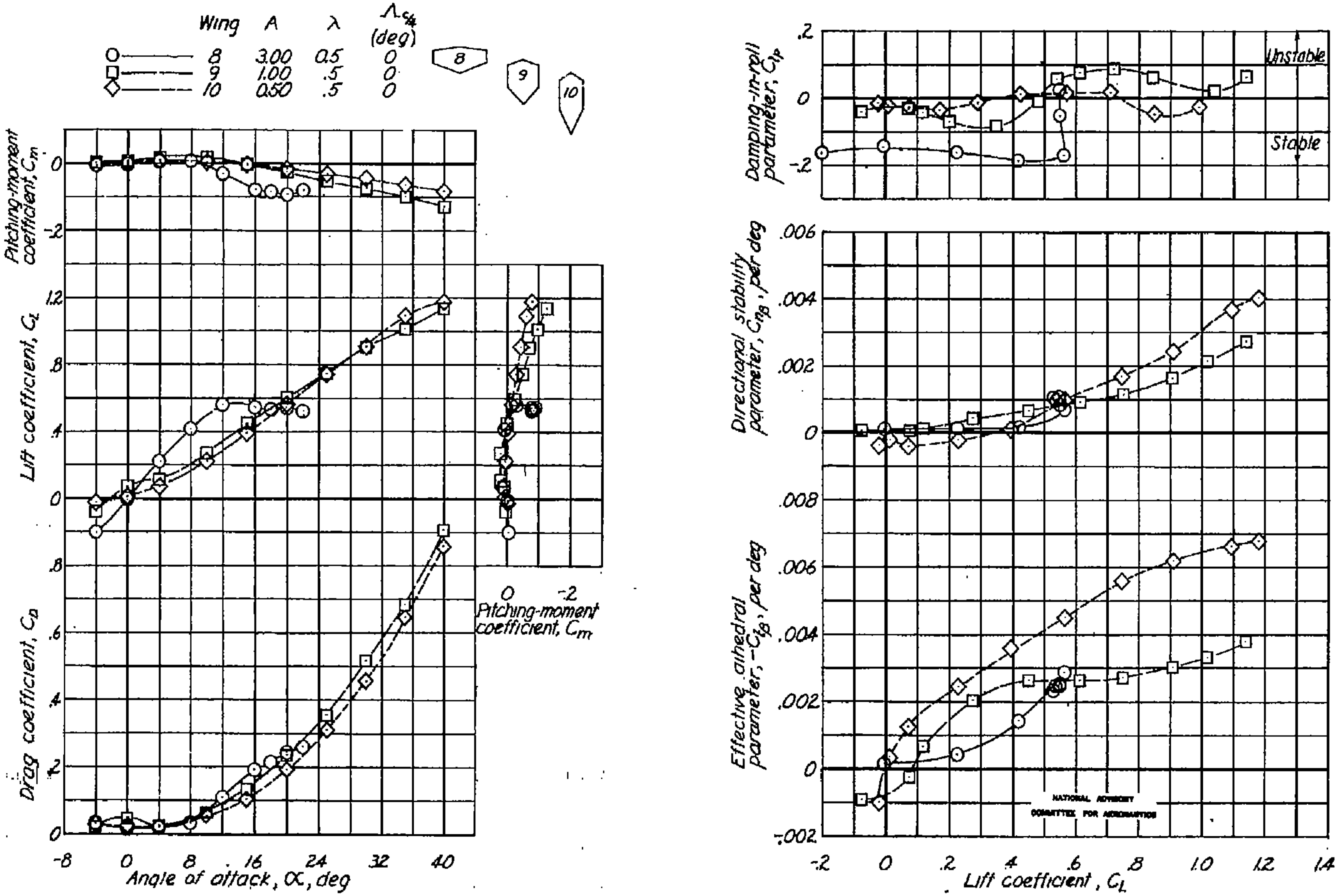


Figure 4.- Aerodynamic characteristics of unswept tapered wings with flat-plate airfoil. (Wings 8, 9, and 10 of Table 1.)

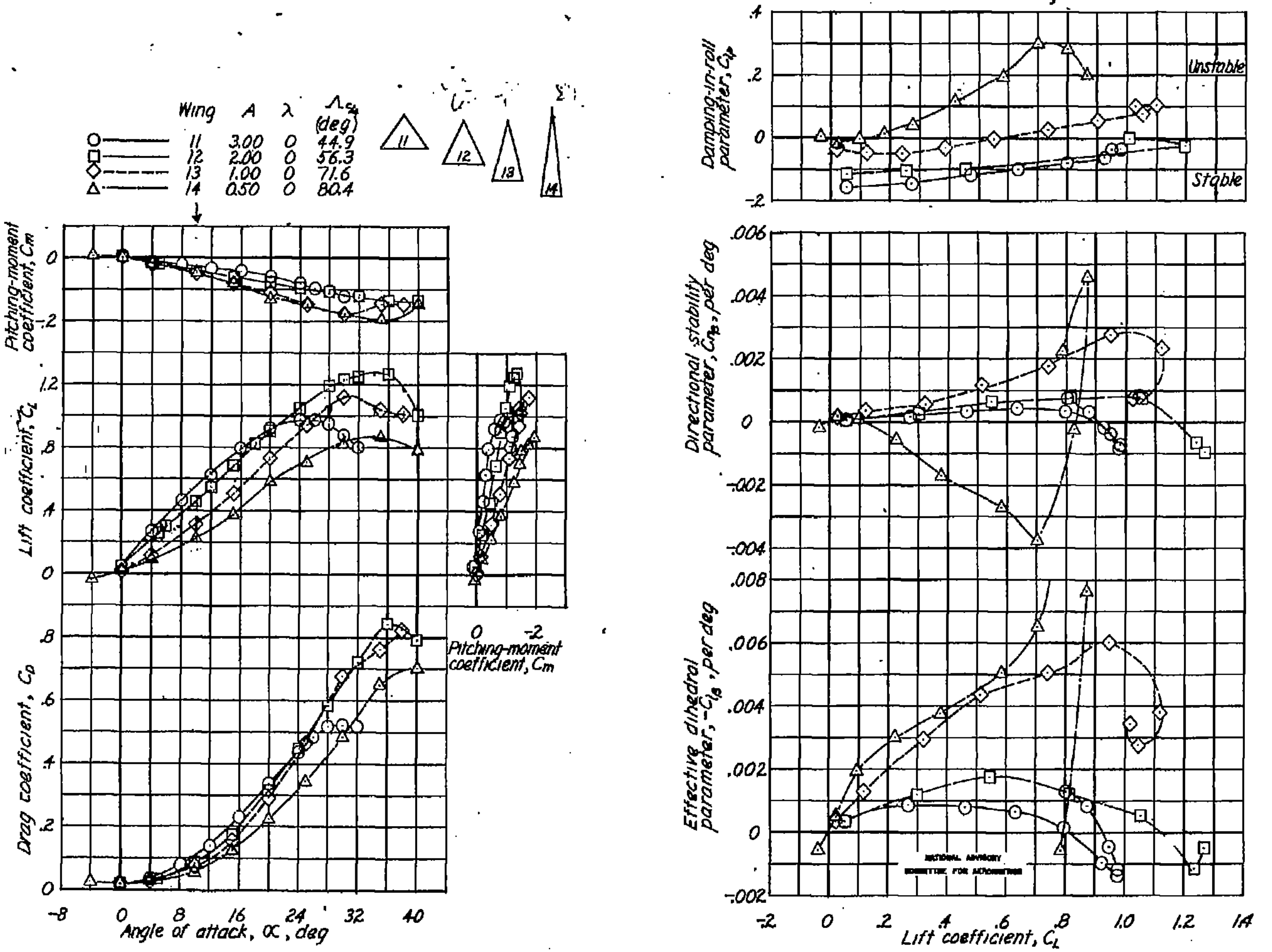


Figure 5.- Aerodynamic characteristics of triangular wings with flat-plate airfoil. (Wings 11, 12, 13, and 14 of Table 1.)

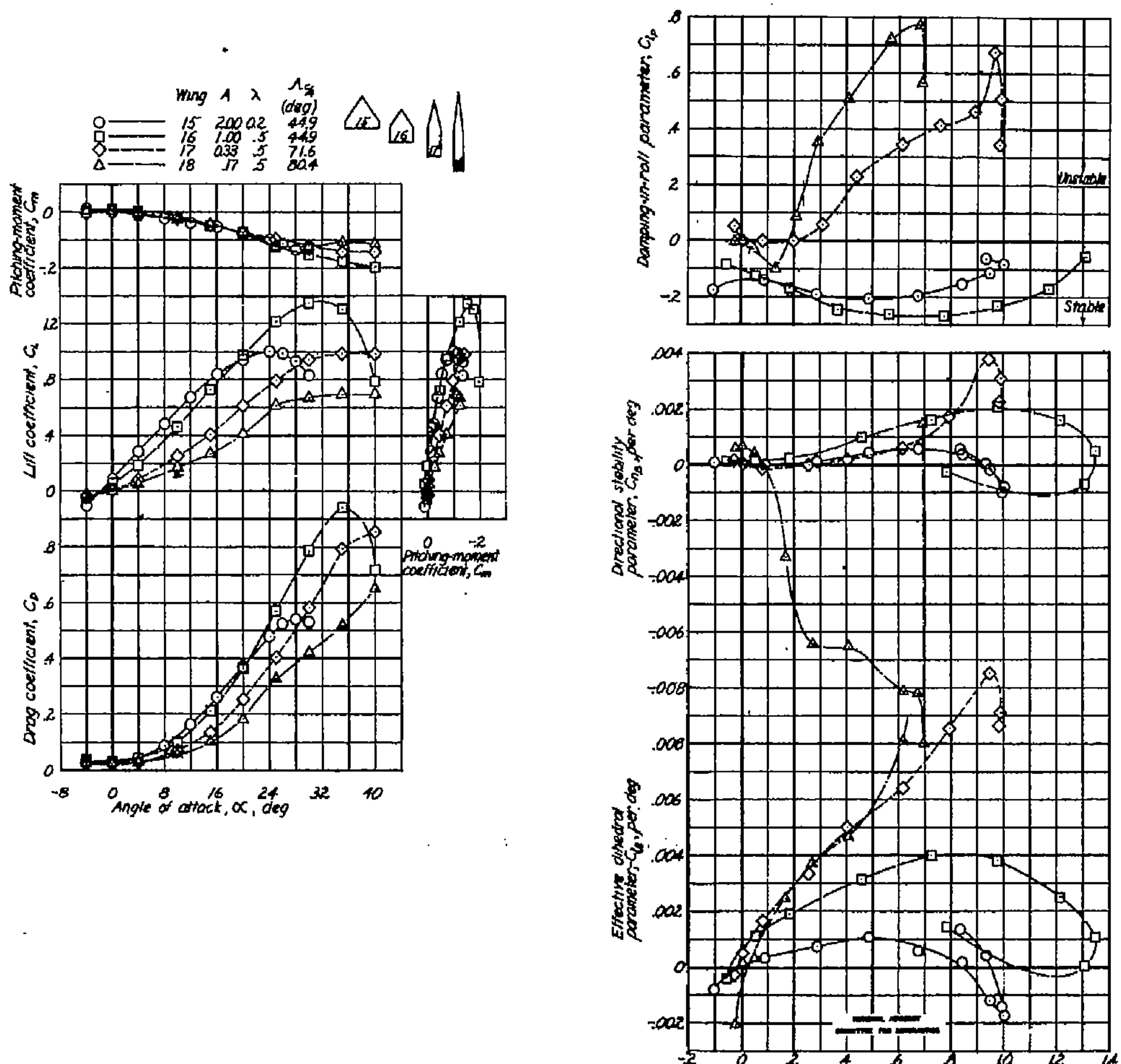


Figure 6.- Aerodynamic characteristics of swept tapered wings with flat-plate airfoil. (Wings 15, 16, 17, and 18 of Table 1.)

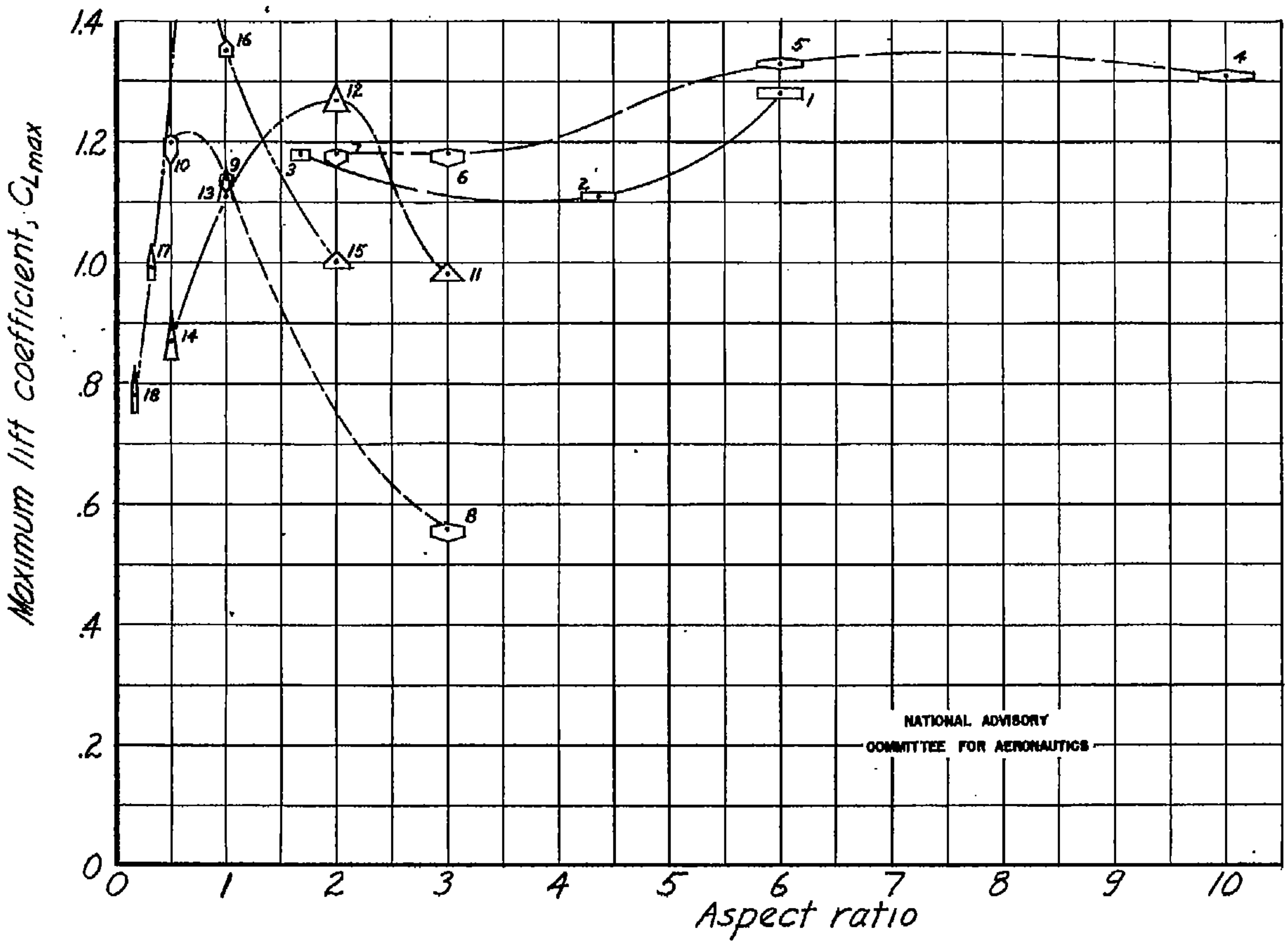


Figure 7.- Variation of maximum lift coefficient with aspect ratio. (Wings 1 to 18 of Table 1.)

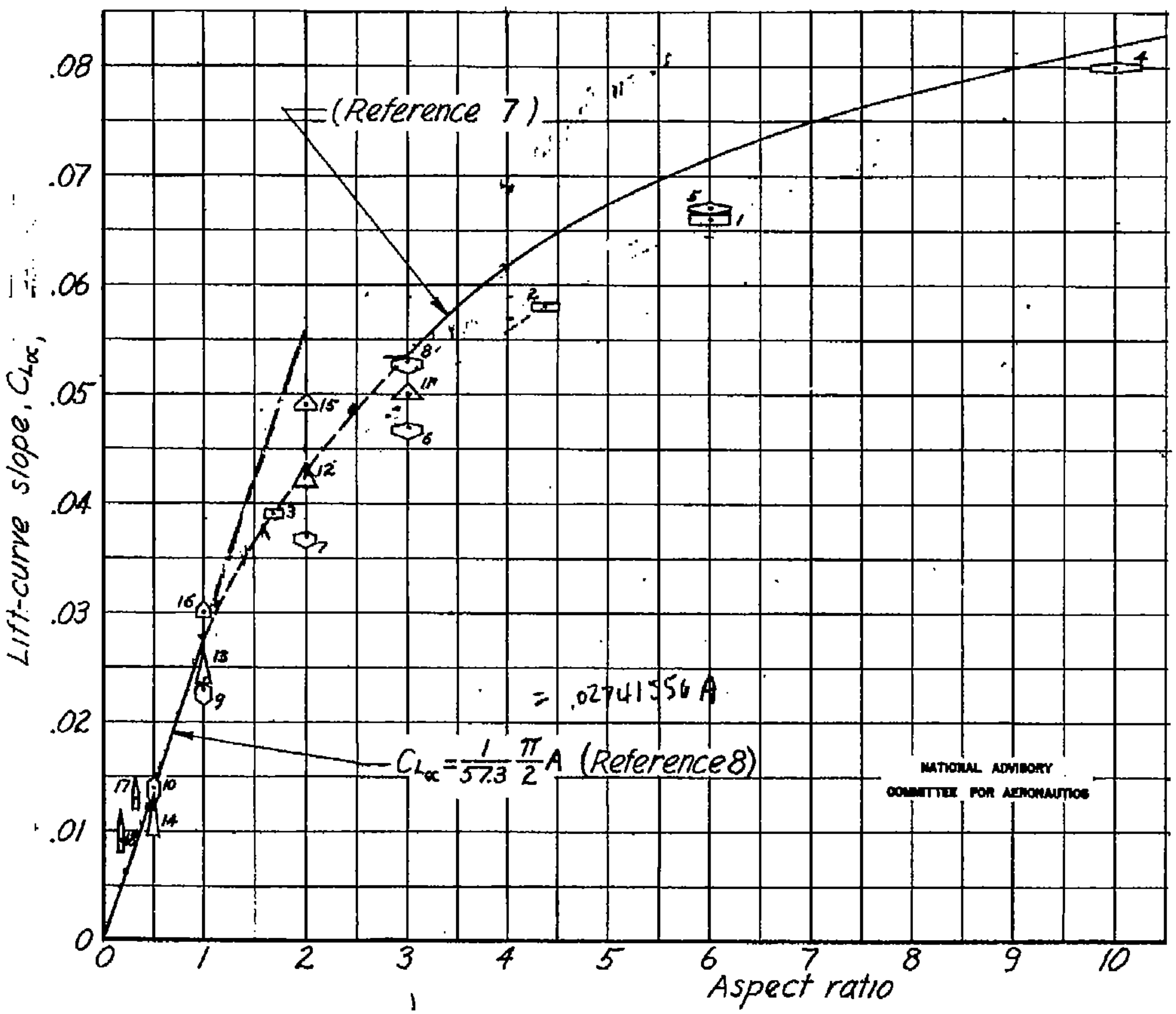


Figure 8.- Variation of lift-curve slope with aspect ratio at $C_L = 0$. (Wings 1 to 18 of Table 1.)

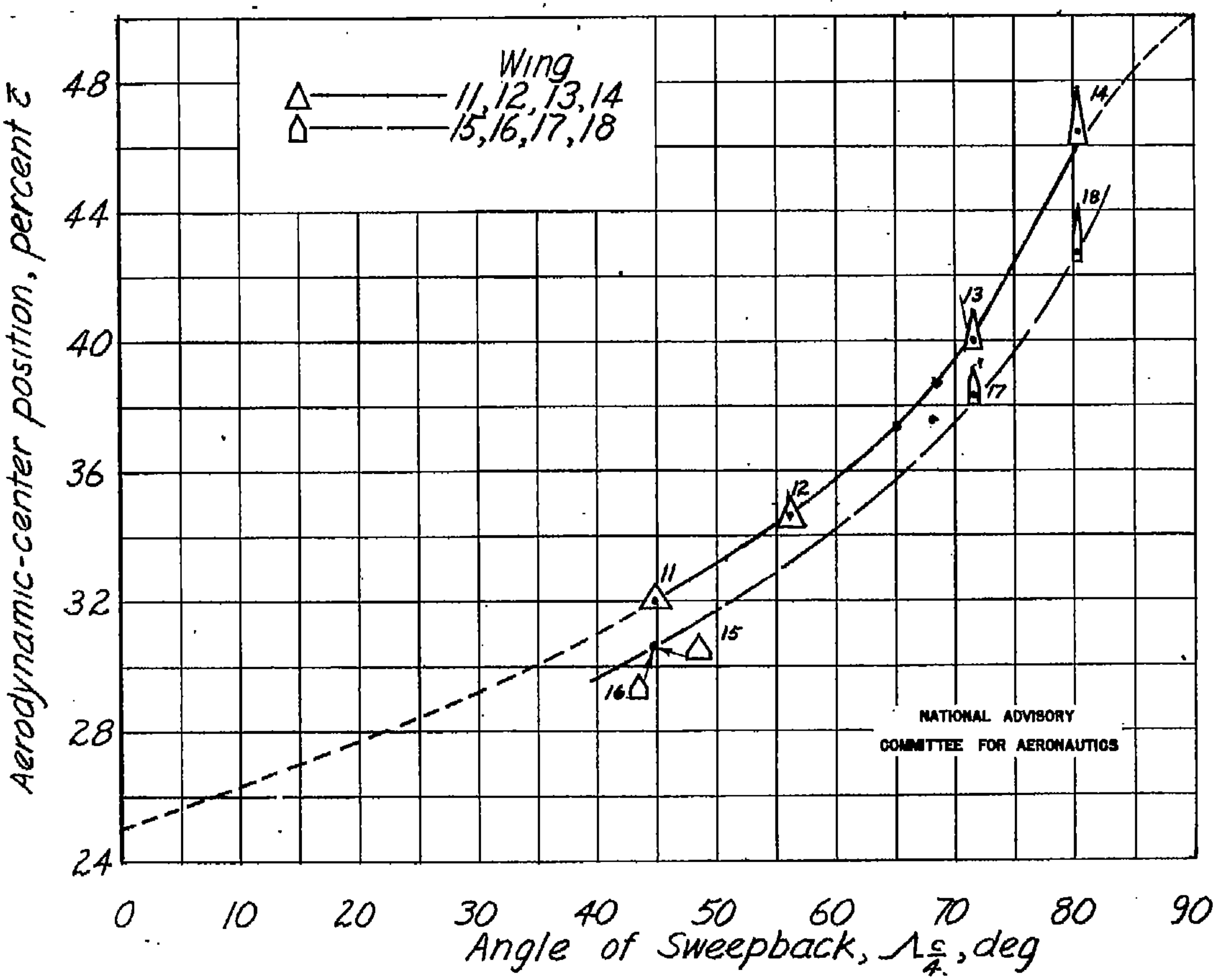


Figure 9.- Variation of aerodynamic-center position with sweepback. (Wings 11 to 18 of Table 1.)

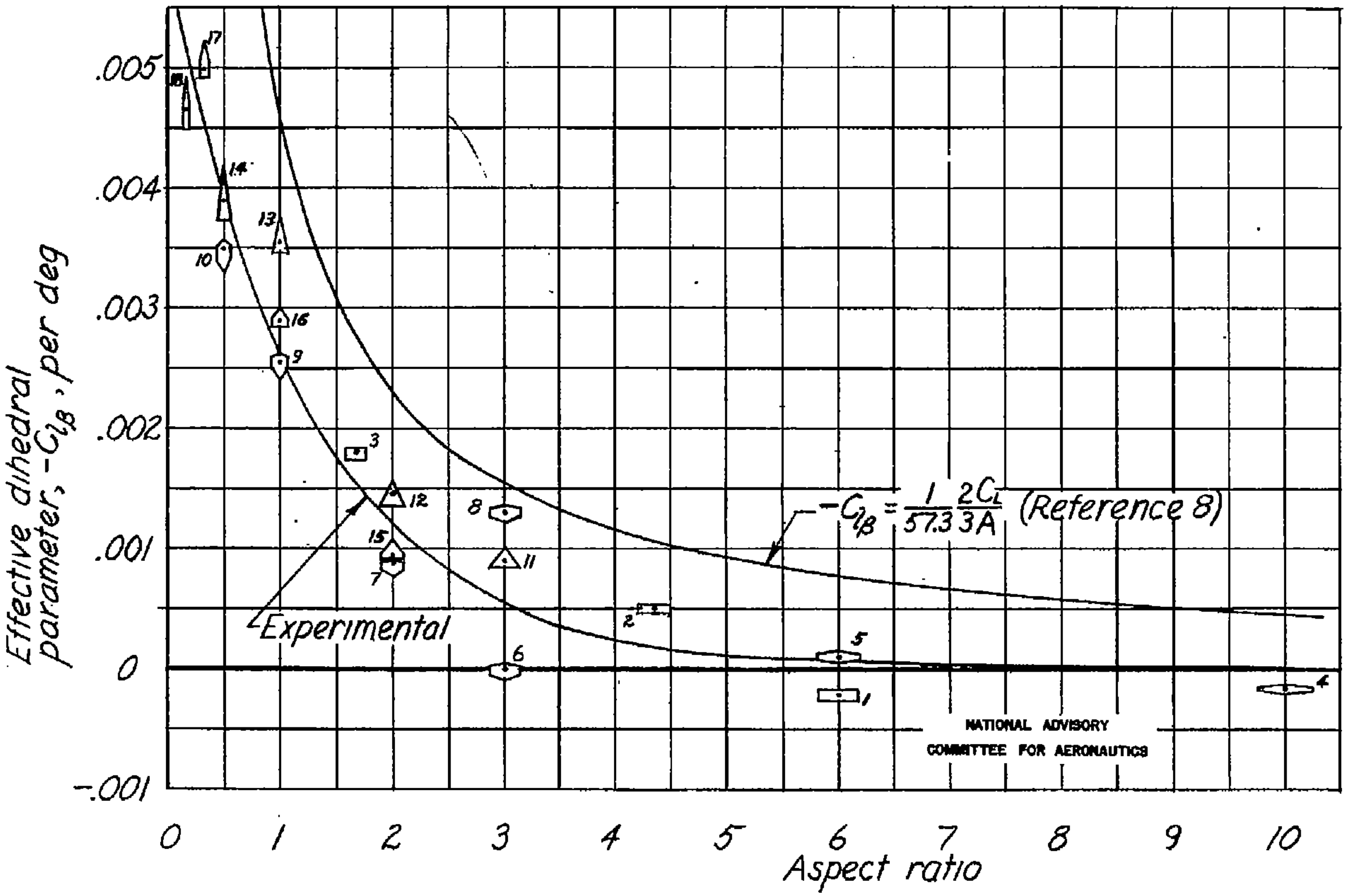


Figure 10.- Variation of effective dihedral parameter with aspect ratio at $C_L = 0.4$. (Wings 1 to 18 of Table 1.)

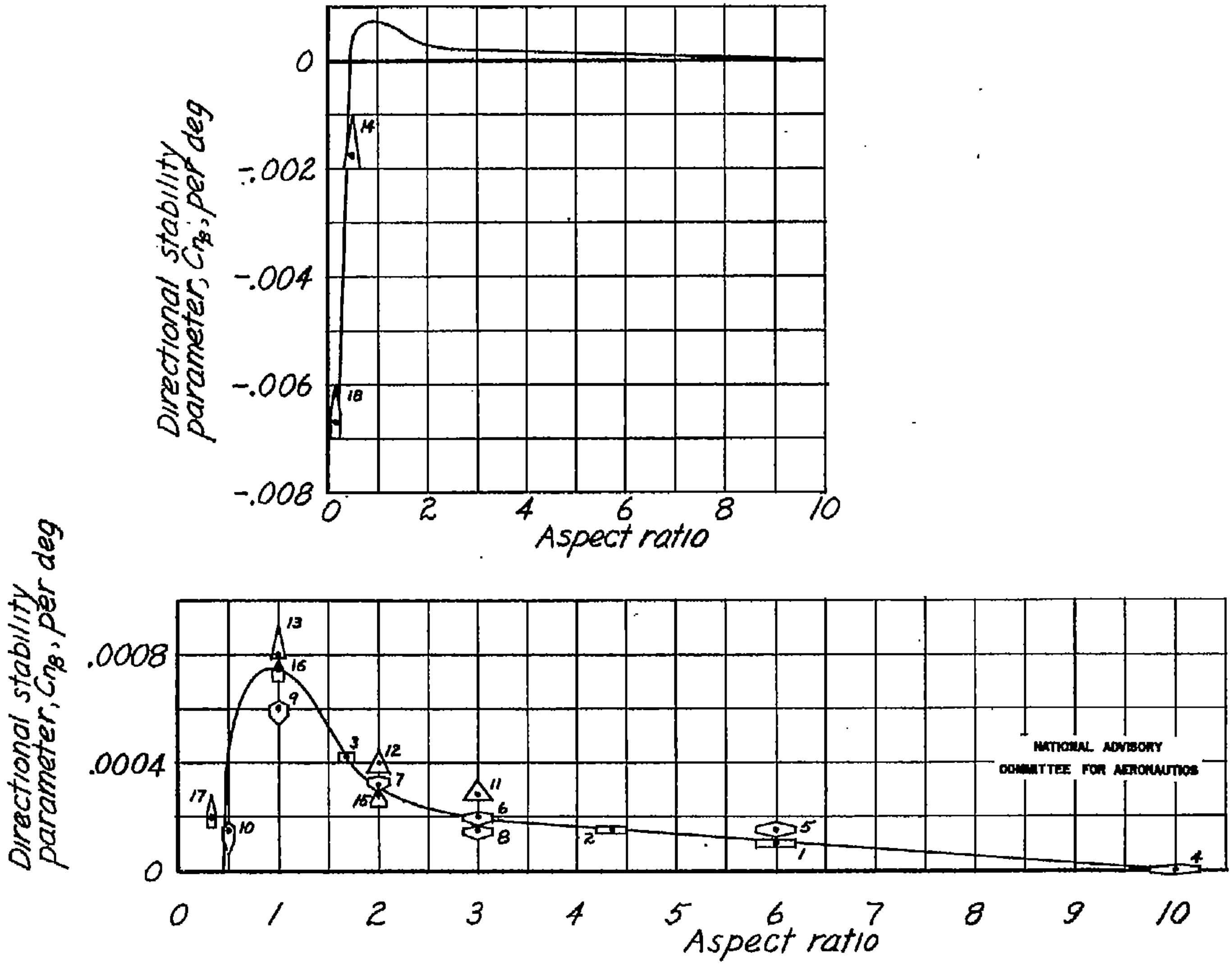


Figure 11.- Variation of directional stability parameter with aspect ratio at $C_L = 0.4$. (Wings 1 to 18 of Table 1.)

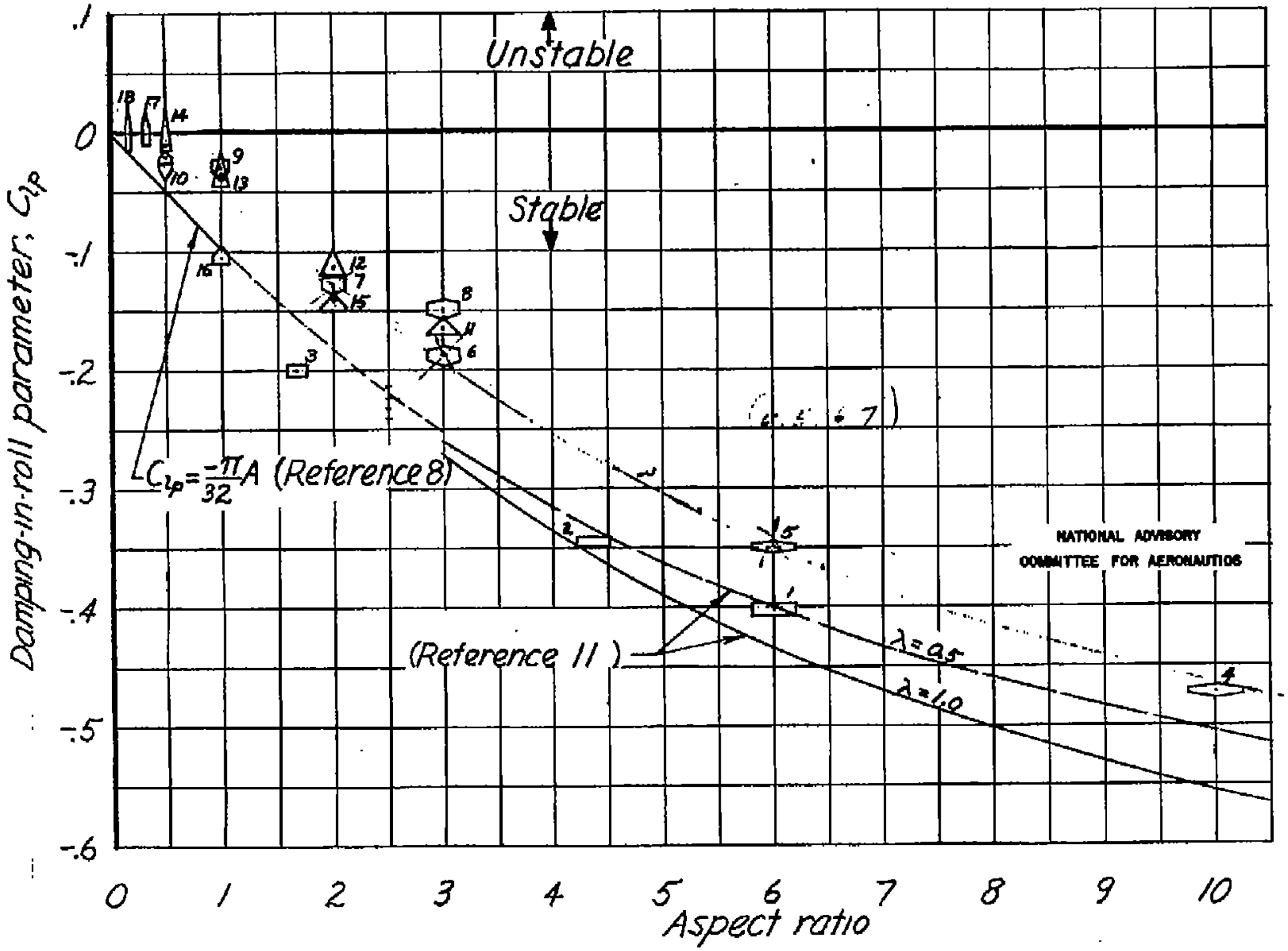


Figure 12.- Variation of damping-in-roll parameter with aspect ratio at $C_L = 0$ for wings 8 to 18 and at maximum values of damping in roll for wings 1 to 7. (Wings 1 to 18 of Table 1.)